

UNIVERSITE DE GENEVE
Institut d'anesthésiologie

FACULTE DE MEDECINE
Professeur M. GEMPERLE

PERCUTANEOUS TRANSTRACHEAL VENTILATION FOR ANAESTHESIA AND RESUSCITATION

THESE

présentée à la Faculté de médecine de l'Université de Genève
pour obtenir le grade de docteur en médecine

par

Beat Walter **SCHAER**

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WYSSACHEN (Berne)

Thèse No 3499

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La Faculté de médecine, sur le préavis du professeur Marcel Gemperle, autorise l'impression de la présente thèse, sans prétendre par là émettre d'opinion sur les propositions qui y sont énoncées.

Genève, le 26 avril 1976

Le doyen :
William Geisendorf

Thèse No 3499



Que le professeur Marcel Gemperle veuille bien trouver ici l'expression de ma vive reconnaissance pour la bienveillance qu'il a toujours témoignée à mon égard et pour avoir accepté la présentation de cette thèse à la Faculté de médecine.

I am indebted to R. Brian Smith, M.B., B.S., chief Anaesthesiologist at Presbyterian University Hospital of Pittsburgh, Pennsylvania, U.S.A., for his advice and assistance.

TO GRISELDA

TO MY PARENTS

In 1956, Jacoby (1) tried to objectively determine values and limitations of transtracheal ventilation in humans. Five patients with malignancy in the upper airway scheduled for surgical procedures under general anaesthesia were put to sleep with incremental doses of sodium thiopental 50 mg. Complete respiratory obstruction occurred, in each patient, as unconsciousness developed. An 18 gauge intravenous catheter was inserted into the tracheal lumen through the cricothyroid membrane, and oxygen was administered at a rate of 4 l/min. He found adequate oxygenation can be maintained by this technique for periods of 30 minutes or longer. However, carbon dioxide is ineffectively removed, and therefore, $p\text{CO}_2$ rapidly rises in apneic patients.

Jacobs (2) advocated transtracheal ventilation as a method for the immediate restoration of an adequate airway in a patient suffering respiratory distress or cardiopulmonary arrest. He used the technique in twelve patients who were comatose and apneic. Oxygen under high pressure (60 psi) was applied intermittently with a volume type ventilator, designed and constructed by Jacobs, through a 14 gauge intravenous catheter inserted through the cricothyroid membrane. Blood gas determinations after 30 minutes revealed a range of $p\text{O}_2$ between 180 and 655 Torr, and a range of $p\text{CO}_2$ between 15 and 54 torr. No serious complications occurred.

Jacobs (3) also reported on the use of trans-tracheal ventilation in 40 apneic and terminally ill patients. Blood gases measured after 30 minutes in 36 patients showed a range of pO_2 between 120 and 650 torr, and pCO_2 between 15 and 54 torr. Intrapulmonic pressures were between 15 and 20 cm H_2O . Spoerel et al. (4), testing transtracheal ventilation first in models found that an oxygen jet through a 16 gauge needle at 50 psi could supply enough force to inflate the lungs, and the flow produced was adequate to supply the tidal volume for an adult patient without air entrainment. He confirmed these findings in dogs, and demonstrated air entrainment of about 44 % of the tidal volume when using an endotracheal tube. The technique was then applied to 12 patients undergoing routine operations under anaesthesia with intravenous agents and paralysis with d-tubocurarine. A plastic 16 gauge catheter was inserted into the trachea and an intermittent flow of oxygen at 50 psi was administered, generated by a Bird Mark 2 Ventilator. Blood gas analysis revealed adequate pulmonary ventilation for periods ranging from 40-75 minutes.

Singh (9) reported 1500 cases of transtracheal ventilation for diagnostic and surgical procedures of the upper airways. There were 1257 cases for bronchoscopy and 135 cases for endolaryngeal surgery. Postoperative ventilatory support was carried out with this technique in 108 cases for a period of 24 to 48 hours.

Airway obstruction occurs frequently in clinical circumstances. In order to find out how the patterns of pressure and volume are influenced by the presence of an obstruction in the proximal or upper airway during transtracheal

ventilation, Chakravarty et al. (5), studied these parameters in a model. They found that obstruction of the airway proximal to the jet tends to increase the time required for inflation and deflation of the lung and also produces a higher inflation pressure, all proportional to the severity of the obstruction.

Soft tissue obstruction above the larynx is not likely to create much resistance to expiration, whereas complete obstruction can be produced by stenotic lesions or by the introduction of an instrument into the oropharynx. It is advisable during laryngoscopy to interrupt the ventilation while the instrument is being introduced and to resume ventilation once the glottis is properly exposed (6).

METHOD

Transtacheal ventilation is based on the Venturi principle. An intravenous catheter introduced into the tracheal lumen through the cricothyroid membrane is attached to a source of high pressure oxygen and acts as a jet generating a positive endotracheal pressure (4). The pulmonary inflation pressure is determined by the size of the transtacheal needle acting as a jet, the pressure applied to it, and the crosssectional area of the trachea. When the jet is turned on, the lungs are inflated by gas emerging from the jet, as well as gas entrained through the upper airway by the negative pressure generated proximal to the jet. As inflation proceeds, the entrainment flow gradually falls as the pressure in the lung rises, until the force generated by the jet is equal to the pressure in the lung. When the jet is turned off the pressure in the trachea will equalize and gas will emerge from the upper airway until the lung pressure has returned to atmospheric

pressure. The flow of high pressure oxygen can be manually interrupted by a simple hand valve (7) or a suitable automatic device, such as the Bird Mark 2 Ventilator.

At Pittsburgh Eye and Ear Hospital, the technique was used for laryngoscopy in 9 instances, for tracheostomy in 7 instances, and for tracheal intubation in 2 instances (table 1). Preoperative medication consisted of 50 mg of pentobarbital, 50 mg of hydroxyzine and 0,6 mg of atropine given intramuscularly 45 minutes preoperatively.

In the operating room, infusion was started intravenously (I.V.), and a peripheral nerve stimulator (Block-Aid Monitor) was attached as well as a cardioscope. Under local anesthesia, a 18 gauge (0,84 mm diameter), a 16 gauge (1,19 mm diameter), or a 14 gauge (1,5 mm diameter) I.V. catheter was inserted into the trachea through the cricothyroid membrane or below the first tracheal ring in the midline. The skin was pierced by the catheter about 1 cm proximal to the point of entry so that a better seal was obtained after the removal of the catheter. Patients were preoxygenated and denitrogenated with an anesthesia circuit and face mask. Sodium thiamylal (5 mg/kg), 2 per cent, was administered followed by 1,5 mg/kg of succinylcholine. After approximately 2 minutes, the patient's lungs were inflated via the transtracheal catheter. The apparatus consisted of a connector for piped oxygen at 50 psi, a pressure adjustment valve, connecting tubing, and a hand-operated release valve, an I.V. infusion extension set, and Teflon I.V. catheter. Ventilation was at a rate of 12/min. with an inspiratory phase of 1 to 1,5 seconds.

Anaesthesia was maintained with intermittent doses of sodium thiamylal and I.V. succinylcholine infusion. Arterial blood gas was sampled before and during anaesthesia.

RESULTS

Twelve patients were ventilated transtracheally during anaesthesia for surgical procedures involving the head and neck. There were 9 instances of laryngoscopy, 7 of tracheostomy, and 2 of tracheal intubation. All patients were adequately ventilated and oxygenated except patients 5 and 12, whose $p\text{CO}_2$ was elevated (table 1). Complications occurred in only 3 patients (table 2). For further illustration two case reports describe transtracheal ventilation using an intermittent jet of oxygen under high pressure in an 11 year old child undergoing operation for laryngeal stenosis and a 6 year old child with mandibulofacial dysostosis, who became obstructed and cyanosed in the recovery room.

Case 1

An 11 year old girl, weighing 46 kg, was admitted to the hospital for tracheostomy, laryngofissure and insertion of a keel. Six years previously, in an automobile accident, she suffered a fractured larynx for which a tracheostomy was performed. One year later the tracheostomy tube was removed and mouth breathing was satisfactory. Over the next five years laryngoscopy was performed on six occasions under halothane anaesthesia without complications.

For several weeks before the present admission, she had slowly increasing dyspnea on exertion. Tomograms of the larynx revealed laryngeal stenosis. Pulmonary function studies suggested an obstructive ventilatory defect : vital capacity (VC) 2,01 liter (79 % of predicted normal) ; forced expiratory volume in 1 sec. 1,37 liter (68 % of VC) ; maximum ventilating volume 23 liter per min. (27 % of predicted).

It was considered that the degree of tracheal stenosis was too severe to permit tracheal intubation. In the operating room, prior to administration of general anaesthesia, a 16 gauge teflon catheter was inserted into the trachea through the old tracheostomy scar. The patient was oxygenated for five minutes and then given intravenous sodium thiamylal (USP) 200 mg as a 2 % solution in water in divided doses. A 0,2 % intravenous infusion of suxamethonium was started. Neuromuscular function was monitored with a peripheral nerve stimulator and, when paralysis occurred, the patient's lungs were ventilated with an intermittent jet of oxygen under high pressure (40 psi). Inspiratory time was approximately 1 second and the respiratory rate 10/min. Anaesthesia was maintained with intermittent doses of sodium thiamylal. After the application of topical anaesthesia to the larynx, 3 ml of lignocaine 4 %, laryngoscopy was performed by the surgeon. Arterial blood was sampled at the end of transtracheal ventilation (15 minutes : $p\text{CO}_2$ was 24 torr and $p\text{O}_2$ was 325 torr). After examination of the larynx, a small endotracheal tube (6 mm I.D.) was inserted. The transtracheal catheter was removed and anaesthesia was continued with halothane and nitrous oxide given through the endotracheal tube.

A tracheostomy was performed and the oral endotracheal tube was replaced by a tracheostomy tube through which inhalation anaesthesia continued. A laryngofissure and keel insertion were performed. Recovery was uneventful. The keel was removed 5 weeks later under general anaesthesia. At laryngoscopy, the airway was found to be adequate. Several days later the tracheostomy tube was removed and breathing through the mouth was satisfactory.

Case 2

A 6 year old girl was admitted to the hospital for removal of carious teeth under general anaesthesia. She was born with obvious mandibulofacial dysostosis which was eventually diagnosed as Treacher Collins Syndrome. Deformation consisted of micrognathia, choanal atresia and deafness. She had dyspnea at birth and a tracheostomy was performed at 2 weeks of age. Between the ages of 3 and 6 years, she had nine surgical procedures performed on her nose under halothane anaesthesia given through the tracheostomy without complications. Several months prior to the present admission, the tracheostomy tube was removed and a small fistula remained at the site of the old tracheostomy.

For the removal of teeth, inhalation anaesthesia with halothane, nitrous oxide and oxygen was employed. Tracheal intubation was performed without difficulty using a 5 mm diameter oral endotracheal tube. At the end of the 15 minute procedure, removal of the tube was uneventful, and she was transferred awake to the recovery room. After a few minutes, upper airway obstruction developed with deep cyanosis. Positive pressure ventilation with 100 % oxygen with the aid of an oropharyngeal airway was unsuccessful. A 16 gauge intra-venous teflon catheter was inserted rapidly into the tracheal fistula. The patient's lungs were ventilated via this catheter with an intermittent high pressure oxygen jet. The oxygen pressure was 30 psi. Inspiratory time was approximately 1 second at a respiratory rate of 10 per minute. The girl's colour improved immediately and no resistance to expiration through the mouth was apparent. Ventilation was continued until the child regained consciousness. The transtracheal catheter was left in place. Difficulty was experienced with spontaneous mouth breathing because of soft tissue obstruction (an oral airway was not tolerated). A tracheostomy was performed and recovery was uneventful.

The cannula was successfully removed from the tracheostomy after several days.

At Eye and Ear Hospital, Pittsburgh, transtracheal ventilation has been used in 52 patients electively prior to and during general anaesthesia. It has also been used to resuscitate 28 patients with acute respiratory distress in the operating room. All patients had pathology of the upper airway. The majority carcinoma of the larynx or tongue. Their ages ranged from 10 to 71 years. Complications are shown in table 3. There were no deaths in this series. All patients were successfully resuscitated. Because of the unusual complications, three cases are reported below.

Case A

A 13 year old boy was admitted for treatment of an anterior laryngeal web. A tracheostomy and insertion of a tantalum keel into the larynx were planned. Because of possible difficulty with the airway, a 14 gauge catheter was inserted percutaneously into the upper trachea under local anaesthesia. Anaesthesia was induced and maintained with intravenous sodium thiamylal 2 % (total 400 mg) and Innovar^R 2 ml. Muscle relaxation was maintained with a drip of succinylcholine 0,2 %. Ventilation of the lungs was performed with intermittent jets of oxygen at 35 psi. Blood gas determination after 10 minutes of ventilation revealed $p\text{CO}_2$ 30 torr and $p\text{O}_2$ 429 torr. The tracheostomy was accomplished uneventfully and anaesthesia was continued through an endotracheal tube inserted into the tracheostomy (Halothane, nitrous oxide and oxygen). After insertion of the tantalum keel, the patient was returned to the recovery room breathing spontaneously.

In the recovery room consciousness was regained, and respirations appeared normal. On auscultation of the precordium, a loud "crunching" sound was heard in systole

and diastole synchronous with heart sounds. Chest X-ray revealed mediastinal emphysema. The following day the "crunch" had disappeared (The description of this sound was first made by Hamman in 1939 during spontaneous mediastinal emphysema). The patient's recovery was satisfactory.

Case B

A 65 year old man was admitted to the emergency room unconscious and in severe respiratory distress. The only history immediately available was from his wife who said that he had an operation of his larynx a year previously, and had gradually become more short of breath. A 14 gauge catheter was inserted percutaneously into the upper trachea, and ventilation of the lungs was performed with intermittent jets of oxygen at 50 psi. Within a few minutes the patient started thrashing around, causing the catheter to become displaced. A large amount of oxygen was injected into the tissues, creating severe subcutaneous emphysema of the head and neck. Tracheal intubation was performed with moderate difficulty, and ventilation was continued via the endotracheal tube.

Results of arterial blood gas taken in the emergency room on 100 % oxygen by face mask prior to resuscitation showed a pH of 7.15, $p\text{CO}_2$ 102 torr, and $p\text{O}_2$ 199 torr. A review of previous charts showed the patient to have chronic lung disease. One year prior to this admission he had a laryngofissure and removal of the left vocal cord followed by a temporary tracheostomy.

A tracheostomy was performed with the endotracheal tube still in place, and the patient was placed on a ventilator. He was weaned from the ventilator after three days. His arterial blood gases prior to discharge showed a pH of 7.41, $p\text{CO}_2$ 54 torr, and $p\text{O}_2$ 65 torr. A chest roentgenogram following the transtracheal ventilation showed moderate mediastinal emphysema.

Case C

A 58 year old male underwent laryngoscopy and biopsy for laryngeal carcinoma.

Anaesthesia was induced with halothane, nitrous oxide and oxygen. After approximately five minutes, total upper airway obstruction occurred. Attempts at tracheal intubation failed. The glottis could not be seen because of distortion of the larynx by carcinoma. Resuscitation was attempted through percutaneous transtracheal ventilation. On palpation of the neck, the trachea could not be identified because of a hard, fixed mass in the neck. The patient by this time was deeply cyanosed. A 14 gauge catheter was inserted in the midline in an attempt to enter the trachea. A large artery (probably the internal carotid) was perforated. The catheter was withdrawn and again inserted in the midline of the neck. This time the trachea was entered. The lungs were ventilated with oxygen intermittently at 50 psi. The patient's color immediately improved. There was some difficulty with exhalation which was relieved by insertion of a bronchoscope into the larynx. A tracheostomy was performed, and the patient made an uneventful recovery.

A total laryngectomy and neck dissection were performed a week later and the patient soon after discharged home.

DISCUSSION

The technique and apparatus for transtracheal ventilation have already been described. In the first child (case 1), a driving pressure of 40 psi was used giving a flow of 150 l/min. with air entrainment. The maximum flow that could be generated would be 2,5 l/sec. and the minimum 0,4 l/sec. With air entrainment the intratracheal pressure reaches a maximum and then decreases as air escapes through the glottis. Thus the tidal volume may not reach 2,5 l. This has been demonstrated by Chakravarty et al. (5).

With the second child a driving pressure of 30 psi was used : there is only a small reduction in the gas flow from 40 psi.

In the first child, some air entrainment probably occurred. A $p\text{CO}_2$ of 26 torr would probably not be achieved in a 46 kg patient with a minute volume of 4 l/min. (0,4 x 10) minimum.

In the second child (case 2), no air entrainment occurred because of upper airway obstruction, as the lungs were ventilated at a flow of 0,33 l/sec. The easy mouth exhalation of oxygen injected into the trachea was an interesting observation in the presence of what appeared to be laryngospasm. Intravenous succinylcholine could have been used in this patient. With the presence of the tracheal fistula and the transtracheal apparatus readily available in the recovery room, the transtracheal technique was chosen. The rationale for the use of the transtracheal technique in the patient with laryngeal stricture was as follows. Because of the narrowing of the larynx, tracheal intubation could have been dangerous, since passage of an endotracheal tube large enough to permit ventilation may not have been possible. Insertion of the

endotracheal tube while adequate ventilation was assured was safer. Also, the transtracheal ventilation allowed the surgeon a clear field for laryngoscopy and inspection of the lesion.

Failure to place the catheter into the trachea correctly at the first attempt is, according to Erasmus (8), an indication to postpone the operation or to administer conventional endotracheal anaesthesia, because air escaping through the previous puncture wound can cause surgical emphysema.

Patients with chronic bronchitis and emphysema are probably not good candidates for transtracheal ventilation because of their diminished compliance. Erasmus (8) describes one such case with the $p\text{CO}_2$ rising to 74 torr.

Local complications may occur during transtracheal catheterization. Hemorrhage may occur at the site of injection, particularly from the thyroid and there is always the danger of perforating the esophagus if the needle is advanced too far. Another possible complication is subcutaneous emphysema. The plastic catheter with the stylet should be advanced until it has just entered the trachea, the position checked by aspiration of air with a syringe already attached, the stylet withdrawn, and the catheter then inserted without the needle. The catheter should be directed caudad at an angle of 45 degrees.

Tissue emphysema can be minimized by entering the skin at some distance from the tracheal perforation site and by pressure on the trachea after removal of the catheter. A soft catheter is more likely to be displaced if it becomes kinked after removal of the needle. For this reason, it is important to fix the catheter more securely. In our cases the catheter was held in position by hand.

Spoerel's group encountered no serious complications in their series of 12 patients. Minor complications consisted of slight swelling of the puncture site, one patient caught up blood-stained sputum, and three had a dry cough. No tissue emphysema was seen in these patients, though it was observed in two others after tracheal puncture with a 16 gauge catheter. Complications may be increased in emergency situations. Complications by the above authors are shown in table 4.

CONCLUSIONS

Transtracheal ventilation may have an important role in cardiopulmonary resuscitation and in ventilation during some types of anaesthesia. It may be of particular value in the patient with a partially obstructive lesion of the larynx, as with carcinoma, in whom endotracheal intubation is difficult. However, in patients in respiratory distress from an obstructive lesion of the larynx there may be problems in exhalation, and it may be necessary to open the upper airway with a small bronchoscope. A dangerously high airway pressure may also occur with a prolonged inspiratory phase with high pressure oxygen. Despite occasional complications, however, the procedure can in many circumstances be lifesaving.

The technique of percutaneous transtracheal ventilation has been used successfully for resuscitation and during anaesthesia for approximately five years. In reviewing the literature, no death and few serious complications have been reported, particularly with the elective use of this procedure.

This technique has established itself as an important adjunct in life support. When used in properly selected cases, its continued use appears justified.

Table 1

No	Diagnosis and procedure	age	weight lb.	catheter size	Air		During anaesthesia			
					pCO ₂	pO ₂	pCO ₂	pO ₂	pCO ₂	pO ₂
1	subglottic stenosis, Laryngoscopy, tracheostomy	23	170	16	26	83	<u>5 Min</u> 36	<u>415</u>	<u>25 Min</u> 37	<u>385</u>
2	Ca larynx, Laryngoscopy, biopsy	33	187	18	34	80	<u>7 Min</u> 35	<u>410</u>		
3	Ca floor mouth postmandibulectomy translabrynthine resection V and LX	60	85	18	34	88	<u>10 Min</u> 33	<u>330</u>		
4	Ca larynx, laryngoscopy, biopsy	66	98	16	24	69	<u>5 Min</u> 36	<u>358</u>	<u>15 Min</u> 30	<u>325</u>
5	Bilateral partial paralysis vocal cords. Laryngoscopy	54	152	18	42	65			<u>15 Min</u> 47	<u>215</u>
6	Ca larynx. Tracheostomy, laryngectomy	63	190	16	30	54	<u>8 Min</u> 35	<u>294</u>		
7	Pharyngeal tumor Laryngoscopy tracheostomy	52	160	14	32	78	<u>5 Min</u> 35	<u>480</u>	<u>20 Min</u> 29	<u>440</u>
8	Ca larynx. Laryngoscopy, biopsy	53	106	14			<u>5 Min</u> 37	<u>360</u>	<u>15 Min</u> 32	<u>250</u>
9	Ca epiglottis. Laryngoscopy Tracheostomy	71	184	14	33	66	<u>5 Min</u> 38	<u>415</u>		
10	Ca larynx. tracheostomy laryngectomy	53	106	14	38	70	<u>5 Min</u> 36	<u>336</u>	<u>40 Min</u> 28	<u>228</u>
11	Vocal cord paralysis. Tracheal intubation, tracheostomy	64	190	14	102	199 (breathing 70% O ₂)			Subcutaneous and mediastinal emphysema	
12	Ca tongue tracheostomy	51	165	14	32	60			<u>15 Min</u> 45	<u>355</u>

Table 2ComplicationsCase 9 (age 71)

Slight subcutaneous emphysema. Obstruction to exhalation relieved with pediatric bronchoscope between vocal cords.

Case 11 (age 64)

Slight mediastinal emphysema from displacement of catheter, forcing oxygen into neck tissue with severe subcutaneous emphysema. Recovery uneventful.

Case 12 (age 51)

Increasing obstruction to exhalation. Sustained intratracheal pressure 30 cm of water relieved with pediatric bronchoscope between vocal cords (pressure measured with water manometer).

Table 3Complications from transtracheal ventilation II

	Elective Prior to Anaesthesia	For acute respiratory distress
No of Patients	52	28
Subcutaneous emphysema	5	2
Mediastinal emphysema	1 ^a	1 ^b
Exhalation difficulty	-	4
Arterial perforation	-	1 ^c

a, b, c see : case reports

Age range 10 - 71 years

All patients had pathology of the upper airway
(63 carcinoma of larynx or tongue).

Table 4Complications from transtracheal ventilation I

Author	Number of cases	Complications
Smith	12	Subcutaneous emphysema 1
		Mediastinal emphysema 1
		Expiratory obstruction 1
Spoerel et al.	12	Tissue emphysema 2
		Dry cough 3
Spoerel Greenway	15	Tissue emphysema 1
Erasmus	20	Tissue emphysema 2
		Hypercapnia 1

Résumé:

Après une revue de la littérature, une méthode de ventilation percutanée transtrachéale utilisée en réanimation et en anesthésie est décrite. L'efficacité de cette méthode a été démontrée chez 12 patients ayant subi une intervention chirurgicale au niveau du larynx.

Sont ajoutés à ces 12 patients 5 cas détaillés dont 2 décrivent des complications de la méthode.

D'après la littérature, on ne relève pas de décès liés à l'usage de cette technique et l'incidence des complications graves qui sont rapportées, est très basse, en particulier lorsque la technique est utilisée de façon éléctive.

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